[redacted]

RESEARCH & DEVELOPMENT
IN THE PHYSICAL SCIENCES

[redacted]

24 January 1964

[redacted]
P. O. Box 2143
Main Post Office
Washington 25, D. C.

Dear [redacted]

[redacted] is pleased to submit for your consideration an unsolicited technical proposal entitled "Automatic Photographic Identification System," TP-191, dated January 1964.

The proposed program is of twelve months duration and will develop a high-resolution, normalizing photo-identification system. [redacted] is proposing the utilization of a data processing technique, which produces a response invariant to image rotation and translation, and is minimally affected by other image variables, such as context and photographic density. This technique was developed by [redacted] and has been successfully demonstrated on other military contracts.

[redacted] will submit interim technical reports and a final technical report thirteen (13) months after contract award. A budgetary estimate for the proposed program is [redacted] on a CPFF basis.

If a technical briefing would aid in your evaluation or more information is desired, please do not hesitate to call [redacted]

Sincerely,

[redacted]
Director of Marketing & Contracts

VB:ss

Encls - Three (3) cpys Technical Proposal
"Automatic Photographic Identification System"

PROPOSED TECHNICAL APPROACH

INTRODUCTION

For purposes of clarity in this discussion, we shall present the identification of photographic imagery as two distinct operations.

The first of these operations is the preprocessing or the normalization of image data; the second, the adaptive pattern-recognition operation which is CONFLEX.[3]

During the normalization process, the descriptors which characterize the imagery are derived by the preprocessing operation. These descriptors should be minimally affected by changes in the imagery which do not affect their classification. Translation and rotation of images are two of the most notable changes which can occur in a scene that must be disregarded in the identification process. Photographic density, aspect, size and context are other variables which can be disregarded under certain circumstances.

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3 Since all pertinent documents and reports relating to the image-processing system and the CONFLEX are in the possession of the customer, the discussion of each system will be kept to a minimum in this document. However, sufficient information will be set forth to acquaint the reader with the fundamental processes involved.

THE NORMALIZING SYSTEM

The first step in the proposed normalizing system consists of scanning the scene under process in a manner which retains the essential aspects of continuity in the imagery. Such a scan is implemented by sweeping a narrow slit across the scene and transducing the integrated level of light intensity for every position of the slit. In this way, the slit aperture integrates the image in one direction, while successive points, in time, correspond to the integrals obtained from contiguous portions of the image in the other direction. Since the data derived from one slit scan are quite limited, it is clear that a number of scans for slits at different angles is required to characterize the scene.

An illustration of a series of line-integral scans is exhibited in Figure 2. Narrow slits, numbered 1, 2, 3, and so forth, are successively swept across the aerial scene, as shown in Figure 2(a), until a full circle is achieved and the sequence begins again. The resulting video signals obtained from such a scanning sequence are similar to those shown in Figure 2(b). If only one object were in the scene under process, the integral scan sequence would produce a series of signatures for that image, one signature for each slit swept across the field. In such a "noise-free" environment, the acquisition of just a few signatures would be adequate for recognition purposes. However, the complexity of most scenes involves a number of objects, the signatures of which superimpose on the output waveform. A larger number

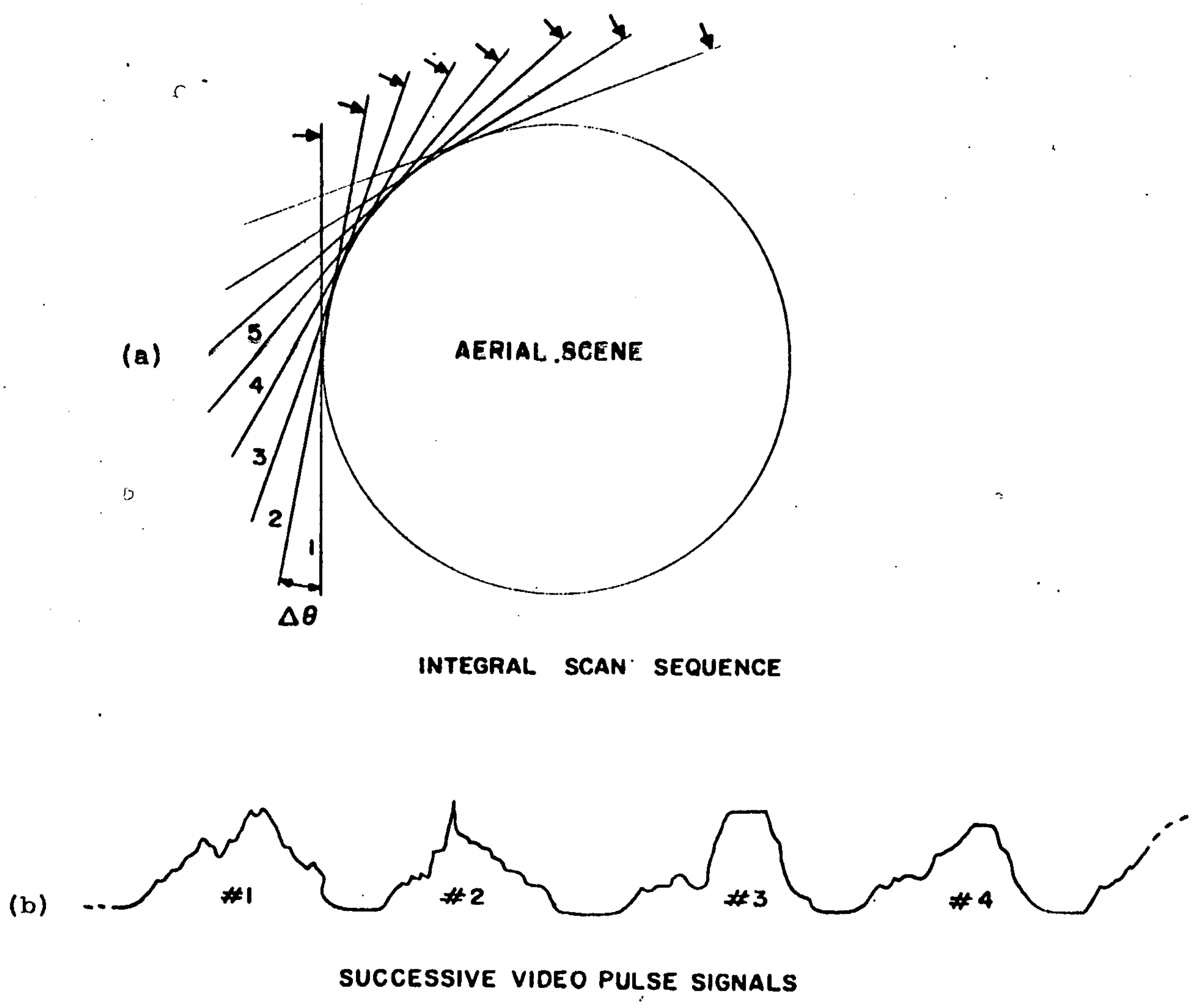

Figure 2. The Integral Scanning Process

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of scan signatures is then required to insure reliable detection of multiple targets. Regardless of the complexity of the scene, a large number of scans can be specified; and, provided the sequence of signatures for the object sought is known, correlation techniques can be successfully applied to the signal-detection problem.

Notice that the effects of image translation and rotation are simple phase shifts in the sequence of signatures obtained. Image translation shifts the signatures back or forth in certain of the sample time intervals, while an image rotation shifts the phase of the entire array of signatures obtained. The set of image signatures may be considered as a set of "one-dimensional views" of the two-dimensional scene. When a sufficient number of one-dimensional views is made, then the two-dimensional scene is completely specified.

A simple method in which the integral scan sequence can be implemented is shown in Figure 3. Sample slits in the form of illuminated slits are imaged onto the scene under process by means of a rotatable mirror mounted at 45 degrees with respect to the axis of the cylinder on which the slits are located. As the mirror rotates, the image of each slit sweeps across the field. The images of successive slits are rotated by an amount equal to their angular separation on the cylinder. The image signatures can be conveniently derived with a multiplier phototube placed on the opposite side of the photographic transparency. A low-resolution scanner operating on this principle is currently in use at [redacted] ST

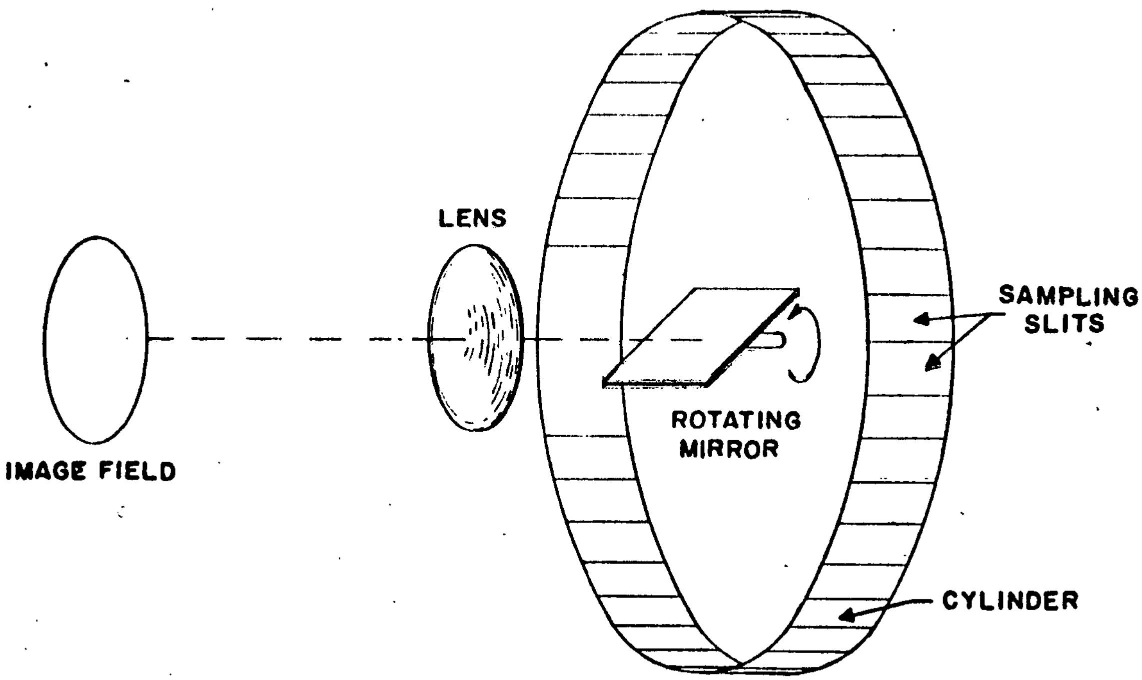

Figure 3. Implementation of Integral Scan Sequence

The remainder of the normalizing system involves the use of filtering techniques which characterize the video signals, independent of their phase, but which take into account the sequence of their arrival for object-recognition purposes. The general method of processing the integral scan sequence is shown in Figure 4. Here, each pulse of the integral scan is evaluated for property content by a multiplicity of property filters, indicated P through P_N. Since the pulse train is cyclic, the output of each property filter consists of a series of pulses cyclic in the same period as the scanning sequence.

The output of each property filter is then further evaluated by separate analysis circuitry designed to measure the cyclic variations in the associated filter output. The circular analysis filters measure characteristics of the periodic input signal, independent of the relative phase of the incoming signal. In this way, the system response to particular target images is the same, regardless of their orientation in the aerial scene.

Two classes of property filters for use with the preprocessing system have been investigated. These are conventional band-pass filters which perform a harmonic analysis of the video signals and matched filters designed to detect the presence of specific pulse signatures. The former class of filters yields a multidimensional description of any particular object and is well suited to processing by an adaptive memory recognition system. On the other hand, the direct matched-filter approach to pulse-signature recognition is an entirely different form of signal detection, best suited to specific and well-defined signals.

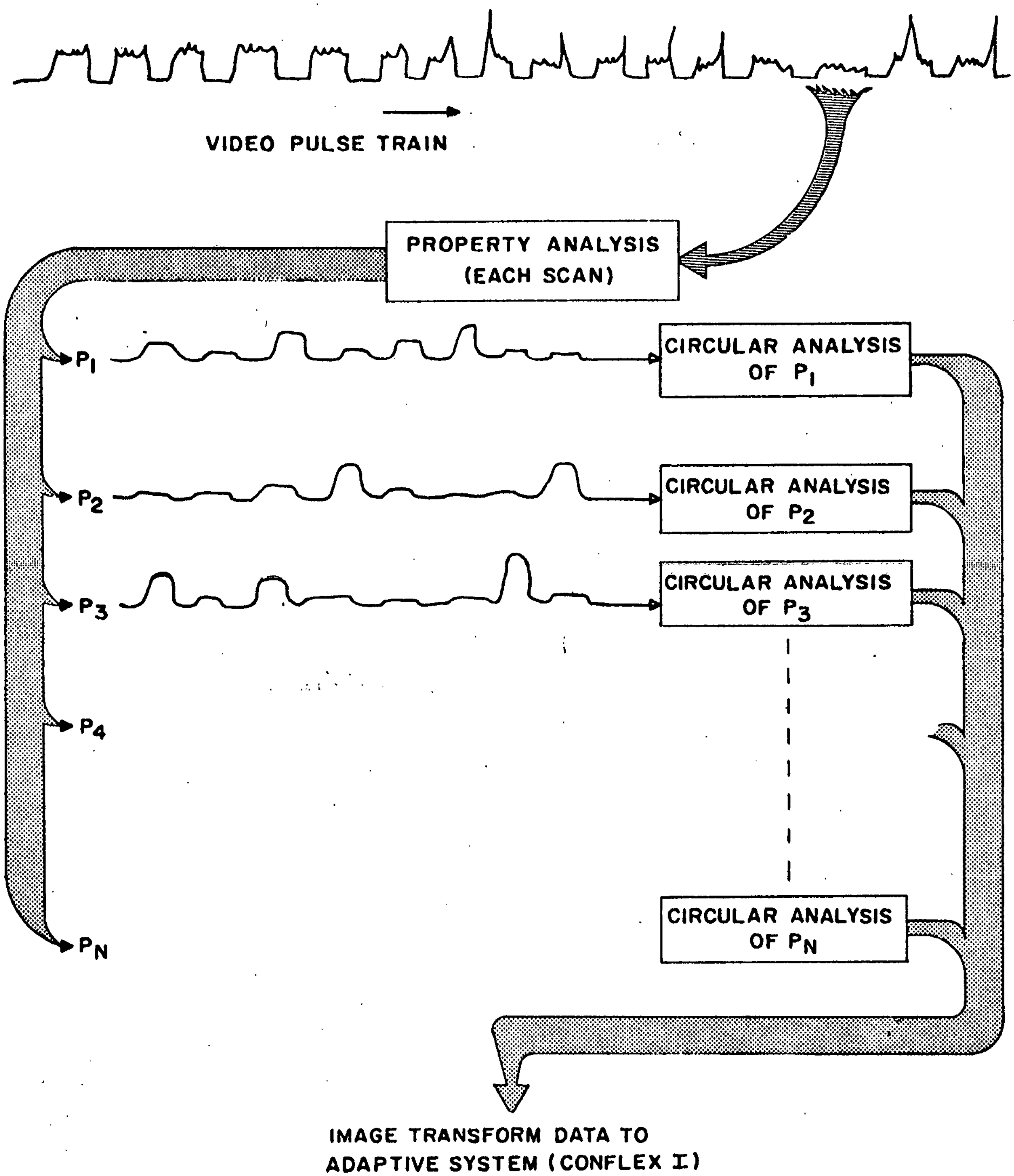

Figure 4. The General Normalizing System

The general form of the system we propose to build is shown in Figure 5. The property filters, shown in Figure 4, take the form of conventional bandpass filters, which results in a property extraction that is a spatial frequency. Since the sampled data are characterized by a cyclic pulse train, the spectrum of the pictorial data is divided into distinct bands, each centered at even multiples of the sampling frequency (fs). The preliminary filter bank is conveniently specified to provide one filter for each band, as shown in Figure 5, to take advantage of the natural frequency separation of the signals.

The output of each preliminary filter is envelope-detected to render a measure of signal strength which is independent of the phase of the signals coming from them. The envelope signal is then processed by a second bank of filters in which the circular analysis takes place. A further look at the spectrum of the video signals makes the prescription of the circular analysis filters quite plain. A number of circular analysis filters can be attached to each preliminary filter, equal to the multiple of the sampling frequency on which the preliminary filter is centered. These filters are also shown in Figure 5.

Auxiliary data concerning the imagery may be derived by combining specific preliminary filters prior to envelope detection. Such phase-coherent data may be detected to supply data supplementing the pure spectral data just described.

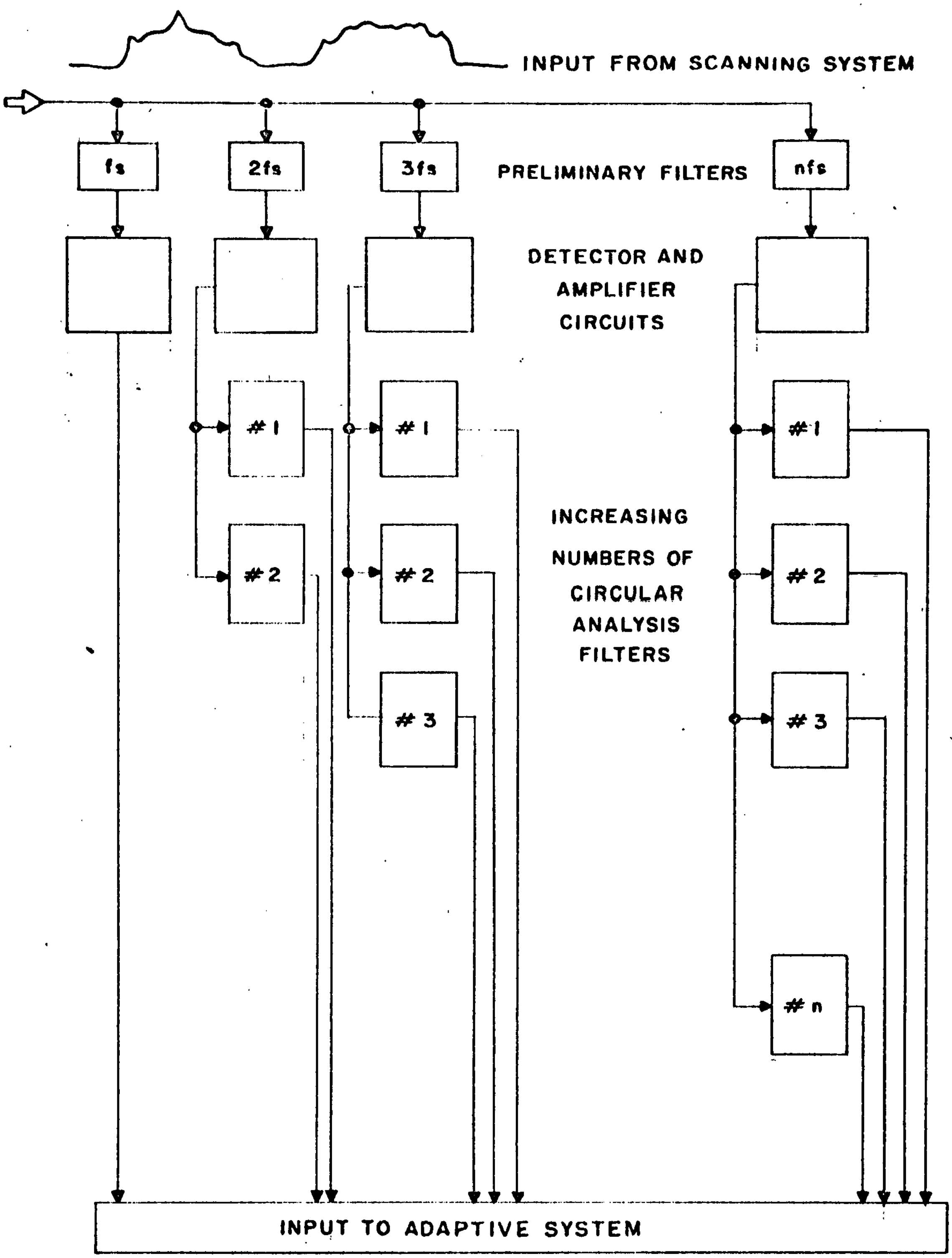

Figure 5. The Electronic Normalizing System

For the reader familiar with the principles of optical spatial filtering, the output of each preliminary filter is explained as being analogous to the output which would be derived by scanning the Fraunhofer diffraction pattern produced by the scene under process. One filter output corresponds to the signal from a circular scan concentric to the dc component image of the point source used in optical spatial filtering and at the radius with locus corresponding to the associated spatial frequency.

The simple electro-optical scanning process afforded by an integral scan sequence provides all the data required to describe the scene under process. Since the scanning process reduces the two-dimensional pictorial data to a convenient amplitude-time function, a practical hardware approach to the pictorial processing problem can be specified. By reducing the data into an essentially two-dimensional density spectrum, position and rotation invariance is attained in the transformation of the data. Since full descriptions of complex scenes are necessarily complex, they involve many channels of spectral data. Processing of the multivariable data is most easily handled through an approach using adaptive pattern recognition. In this way the difficult problem of designing recognition circuitry for specific complex patterns can be avoided.

CONFLEX I

As stated in the introduction to this proposal, an adaptive pattern-recognition system, CONFLEX I, has been designed and built by [redacted] Repeated experiments have successfully demonstrated that literally thousands of complex patterns can be used as a data basis for recognition tasks in the CONFLEX System. Therefore, it has become evident that CONFLEX is particularly well suited to process the data derived by the normalizing system. Although detailed descriptions of CONFLEX may be found in the documents referenced in Footnote 3, a brief description will be given here for the sake of completeness.

TAT

The CONFLEX System consists of three major classes of processing and logical elements:

1. Sensory Cells (S-Cells)
2. Discrimination Cells (D-Cells)
3. Memory Cells (M-Cells)

The S-Cells are simply the input transducers which produce electrical signals in accordance with the input patterns. If the input pattern is already in the form of voltage or current sources, then no transducer is required.

The D-Cells are threshold circuits which receive inputs from some arbitrary group of S-Cells and which generate a digital output determined by the pattern or the S-Cells selected.

The M-Cells are those elements which accumulate information or classes of patterns and act as the stored reference functions with which the processed signals from new patterns are compared.

Further details of the system will have reference to the block diagram shown in Figure 6.

The input data facility currently in use with the CONFLEX I consists of 400 light-sensitive resistors arranged in a 20 x 20 matrix. The optical input has been selected for convenience, and the use of electrical inputs such as those obtained from the normalizing system can be processed directly with little modification of existing hardware.

The D-Cells in CONFLEX number 5000, each of which has inputs from approximately 100 of the 400 sensors. The inputs to a D-Cell are divided equally into two groups; one group contributes positive current, and the other, negative current. All current contributions are proportional to amplitude of the signal at each sensor. On the average, the sum of the currents to each D-Cell is zero. Digital outputs of +1, 0, or -1 are generated by the D-Cell for respective conditions of net current greater than some positive threshold current, in the neighborhood of zero, or current below some negative threshold. The D-Cells generate a 5000-element word for each pattern presented to the system. While the system is being programed, the successive D-Cell representations of all patterns ascribed to one class are accumulated by 5000 memory cells, one memory cell for each D-Cell. Data on each class to be recognized are accumulated in separate banks of memory cells.

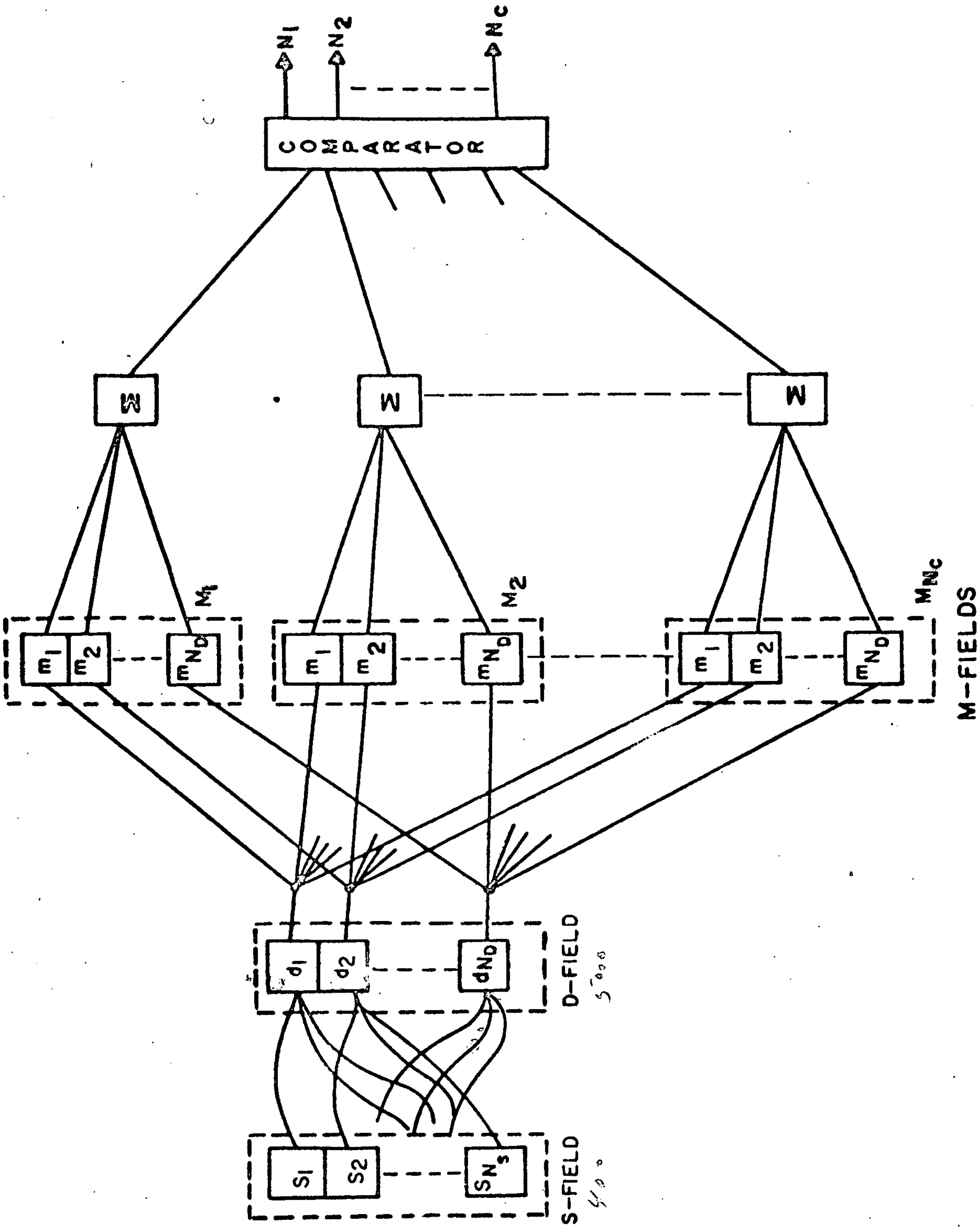

Figure 6. Block Diagram, CONFLEX I

After the training process is completed, each bank of memory cells contains a statistical model of the D-Cell representations for patterns belonging to the particular class. In the RECOGNIZE mode of operation, the D-Cell representations of new patterns are compared with all memory stores by a correlation process. Class assignment can be based on one of two criteria. If class models exist for all possible input patterns, a class assignment can be made to the memory store which correlates most highly with the D-Cell representation of the new patterns. In other problems, it is more practical to associate with each memory a threshold value. If the correlation with the D-Cell representation of the new pattern exceeds this threshold, then a class assignment is made. Multiple class assignments are possible in this mode of operation, inferring that patterns belonging to several classes are superimposed on the sensory (S-Cell) field.

In the LEARN mode of operation, patterns can be trained to the CONFLEX System in just under 17 milliseconds. In the RECOGNIZE mode, the same time interval is required to compute the correlation value for each class in process. Up to 48 classes are available when the simple decision scheme described here is utilized. Since the adaptive pattern-recognition system needed to process the complex data in the transformed image data is physically established, the emphasis in the proposed program will be the construction of the normalizing system. Output signals for the normalizing system will be designed so that a minimum of interface hardware is required. Using the CONFLEX equipment, a great deal of experimental data can be obtained to test the capabilities of the normalizing system.

SYSTEM IMPLEMENTATION

The tentative system specification considered adequate to meet the objectives of the program is primarily dictated by the resolution of the optical scanning system. The tentative plans call for an integral scanning system which executes 100 integral scans per cycle of data samples, one scan every 3.6 degrees of arc.

Using a rotating-mirror implementation, we expect that a complete scan sequence can be taken in 16 milliseconds. Optical resolution in excess of 300 lines can be obtained for video signals of bandwidth of two megacycles. A minimum of 25 preliminary filter channels will be associated with the scan signal to take advantage of all spectrum channels which are completely resolved. Over 500 channels of circular analysis data are defined by the 25 preliminary filters; however, only one-half of these appears necessary to supply adequate density spectrum data to accomplish the desired objective. Supplementary data channels will be supplied by auxiliary circular analysis of several preliminary filter outputs combined before envelope-detection takes place.

The complete breadboard system will provide approximately 400 discrete output channels, each of which will be introduced to CONFLEX for the adaptive training and recognition functions. The optical scanning system will be designed to accept aerial photography in various formats, but in particular, provisions will be made to work with 35 millimeter slides. In this way, use can be made of an existing library of photographic material at $\boxed{}$ Supplemental material for use in the experimental work will, of course, be welcome and useful.

PROPOSED SCHEDULE

The program of the proposed design, development and experimental work would be carried out in three phases, spanning a total period of one year.

PHASE I

Phase I of approximately two months' duration would be devoted to the hardware design of the scanning and filtering system. Final choice of design parameters would include the number of scans in the sequence and the resolution to be used in the circular analysis. Scanning speeds and required video circuits would also be determined at this time.

PHASE II

Phase II of approximately six months' duration would be devoted to construction of the breadboard normalizing system. Preliminary testing of the electronic filter system would be carried out near the end of this phase with simulated signals.

PHASE III

Phase III of four months' duration would be used exclusively for testing the breadboard system. A rather long period of testing is recommended because the measures of system capability encompass a broad class of problems. It is anticipated that the final results of the extensive experimental program would be the basis for specifications governing operational systems designed to handle particular problems in automatic photo identification.

Interim engineering reports would be supplied at appropriate milestones in the program, and a final report would be prepared at the conclusion of the program, to include information concerned with all phases of the effort.